



Practical Issues in Applying a Programmable Holographic Optical Element for Optical Metrology

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by
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Outline

- Objectives / Challenges
- System Design
- Simulations
- Calibrations and error analysis
- Compensation : Tilt, Cylinder wavefronts, Mandrel
- Conclusions / Problems to be solved

Objective

The overall objective: to produce, demonstrate, and deliver a dynamic, holographic interferometry inspection for a wide range of advanced optical components including aspheric optics.

Specific Objectives

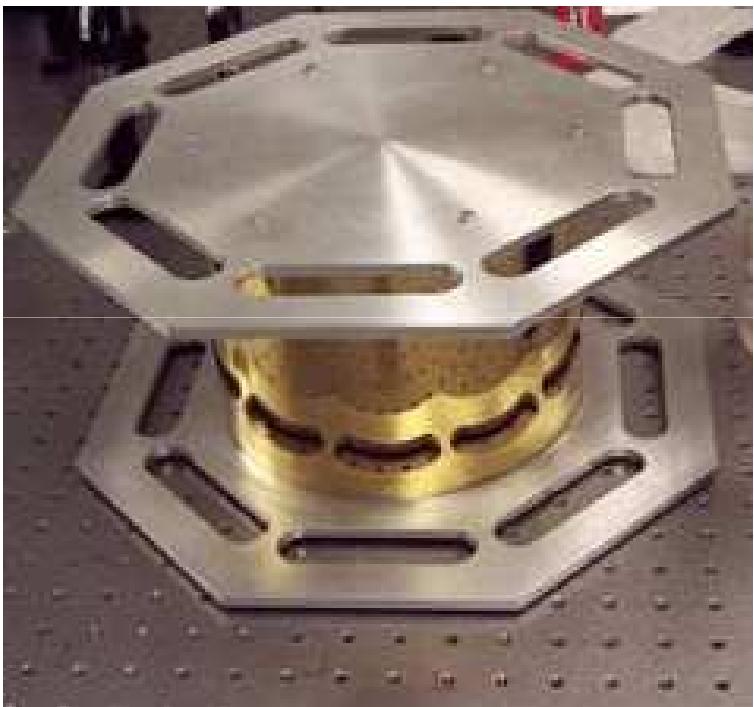
- Model the measurement problems of interest and solutions.
- Adapt the MetroLaser's PhaseCam technology.
- Incorporate the Spatial Light Modulator to expand the dynamic range.
- Produce and deliver a system that is capable of measuring the NASA's Mandrel.
- Demonstrate measurements of other optical components.
- Design, construct, and deliver the complete system to NASA GSFC.

Challenges

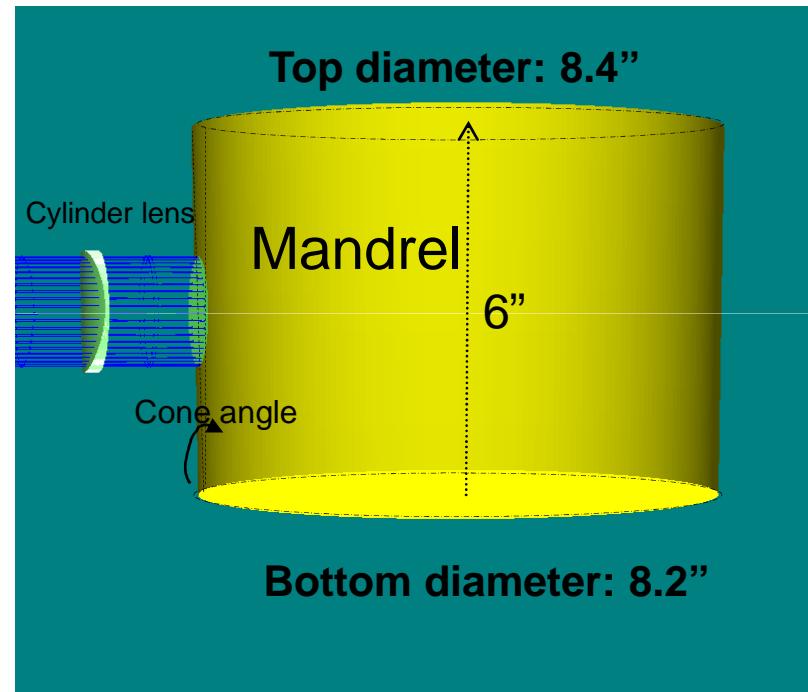
- Some components produce too many fringes for conventional interferometry
- Develop a metrology system using a programmable HOE (SLM) to reduce the numbers of fringes for aspherics
- Calibration of the SLM
 - Phase-only mode by controlling polarization
 - Corrected gamma curve, i.e. linear phase shift versus grayscale value
- Mandrel provided by NASA GSFC
 - Mandrel is 6 inches tall, top and bottom diameters are 8.4 / 8.2 inches respectively.
- Identification of errors and noise
- Stitching software

Mandrel to be measured

Photo of the Mandrel

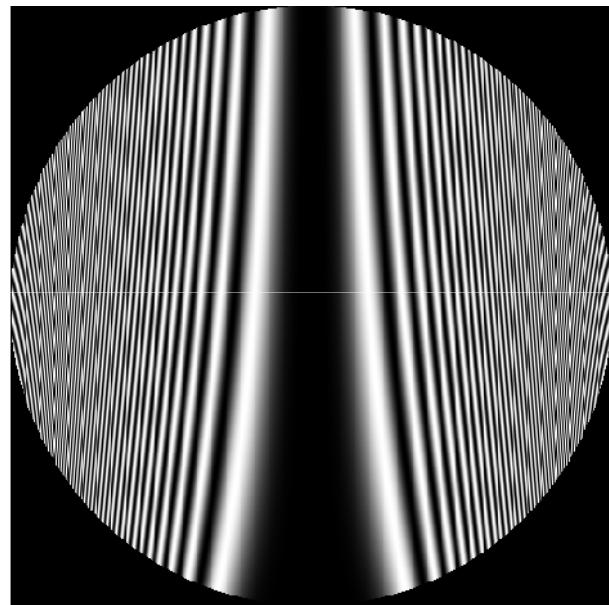


Geometry of the Mandrel

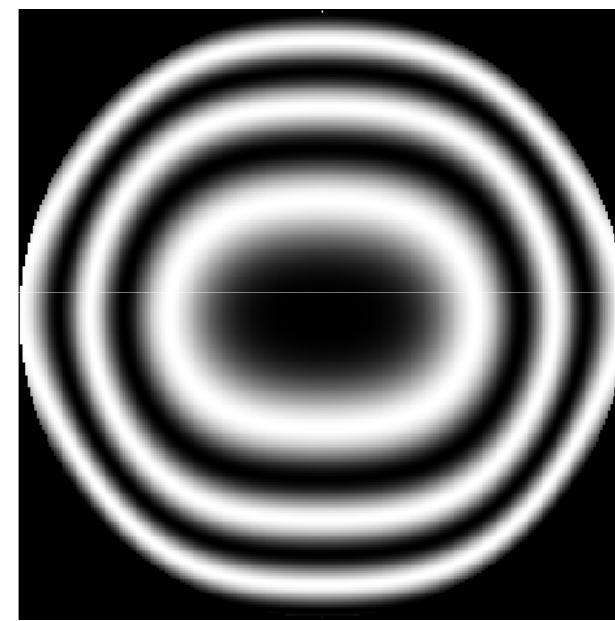


- Mandrel provided by NASA GSFC, 6-inches tall, top and bottom diameters are different, cone shape.

Too many fringes for conventional interferometry



Simulated Mandrel fringes



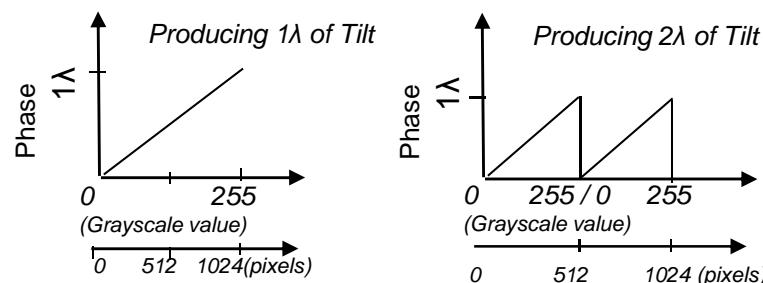
Compensated fringes

Null lens optics, CGH methods can be used but require new CGH for every item.

Key Components: SLM, Pixelcam*

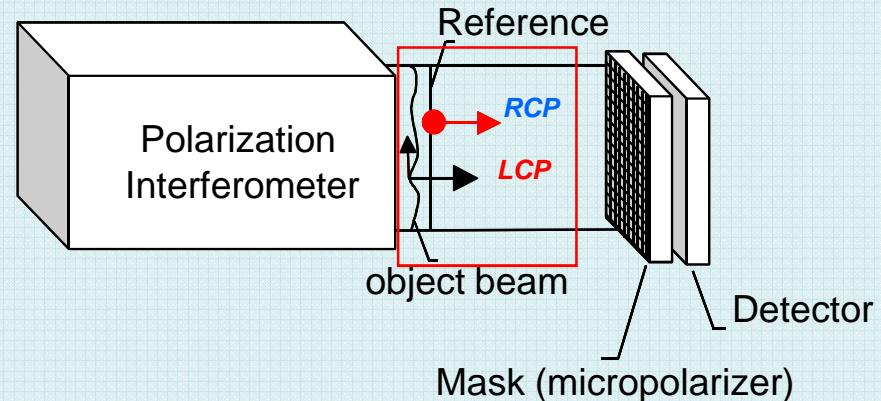
SLM for a compensator

- Programmable holographic optical element
- Produce wavefronts of any shape and can simulate freeform optical surfaces
- Holoeye SLM
 - SLM can produce a phase up to 2π at 632.8nm
 - Assign 0 to 255 grayscale values to 0 to 2π (or 1λ)
 - Can generate higher phases by wrapping phase / tilt example will be shown
 - Can provide more than 150 wave tilt
 - Pixel size ~ 19 microns.
 - 19.5 x 14.6mm size(1024 x768 pixels)

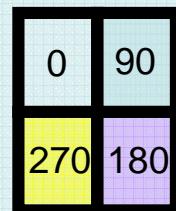


Pixelated Phasacam for a detector

- Spatial phase shifting interferometer
- Single shot, insensitive to vibration



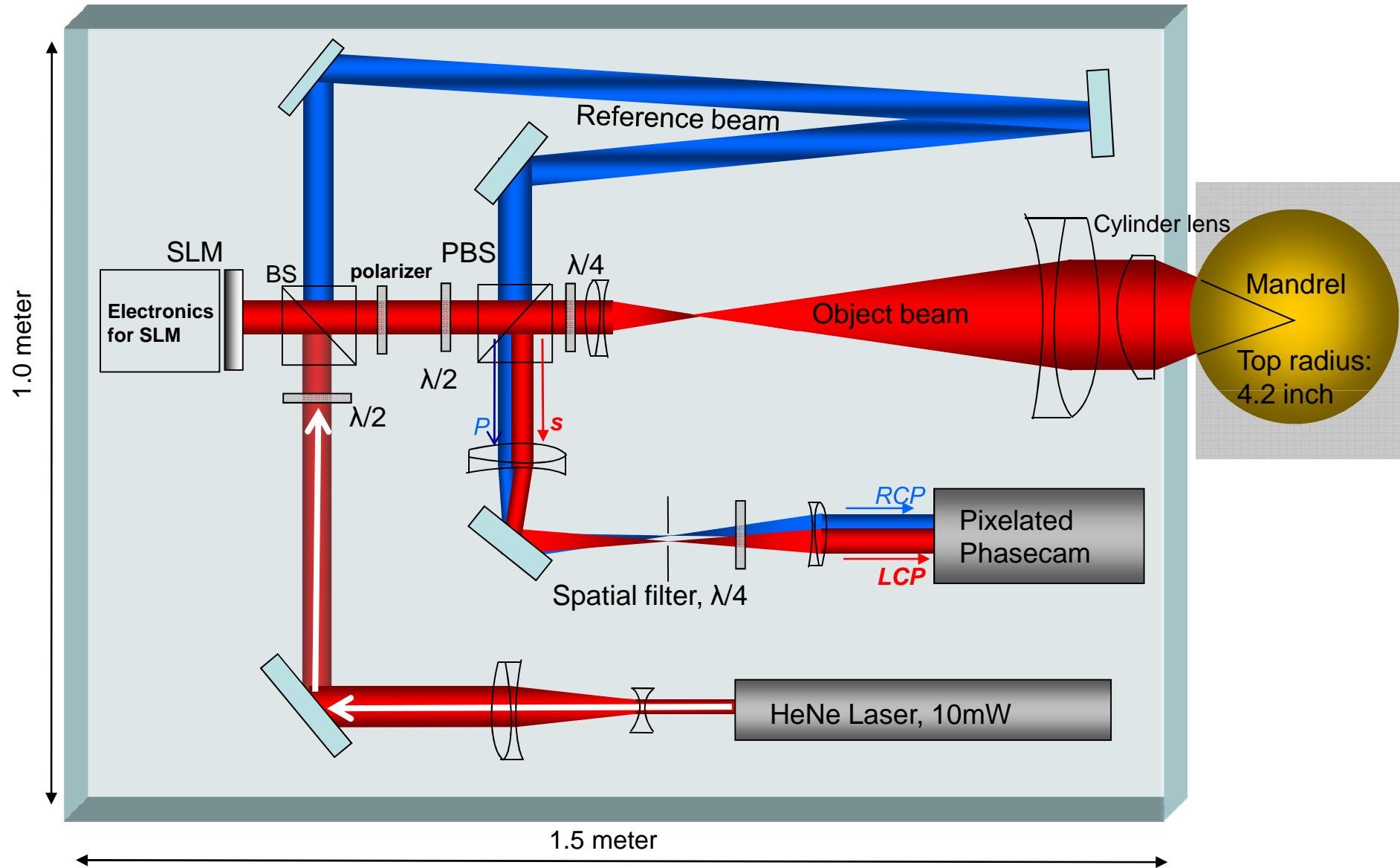
Phase information of the object, $\Delta\phi(x,y)$ can be obtained from the 4 intensities on each unit cell.



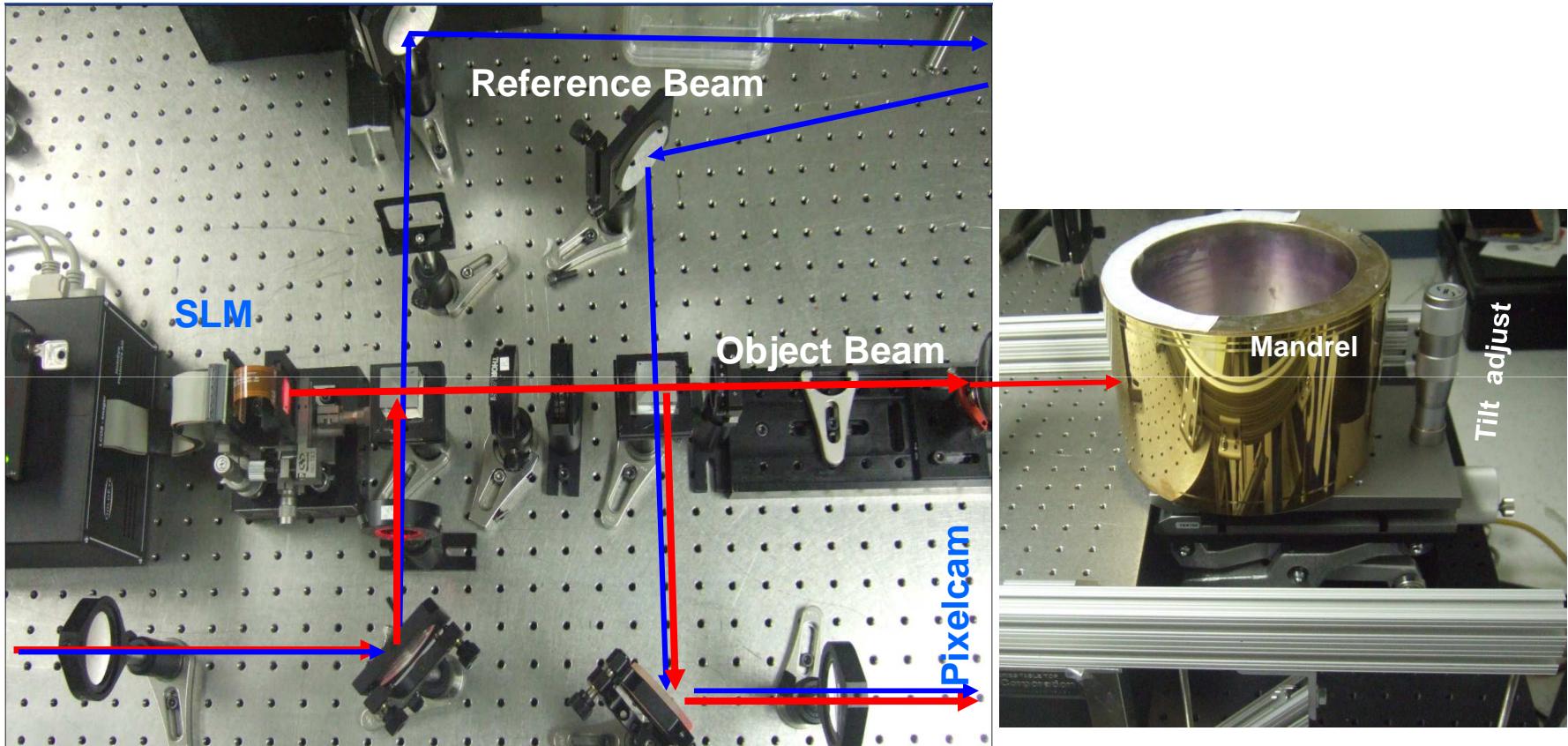
$$I(x,y) = \frac{1}{2} (I_r + I_s + 2\sqrt{I_r I_s} \cos(\Delta\phi(x,y) + 2\alpha_p))$$

*Produced by 4D Technologies, Inc, Tucson, AZ
<http://www.4dtechnology.com>

System Design (Top view)



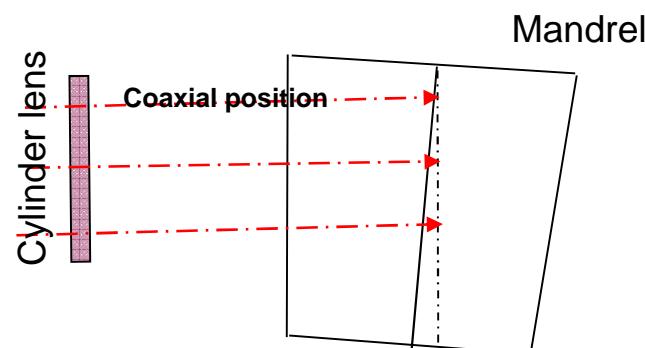
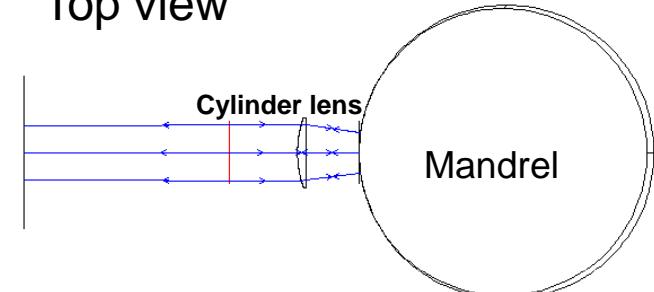
System Design, II



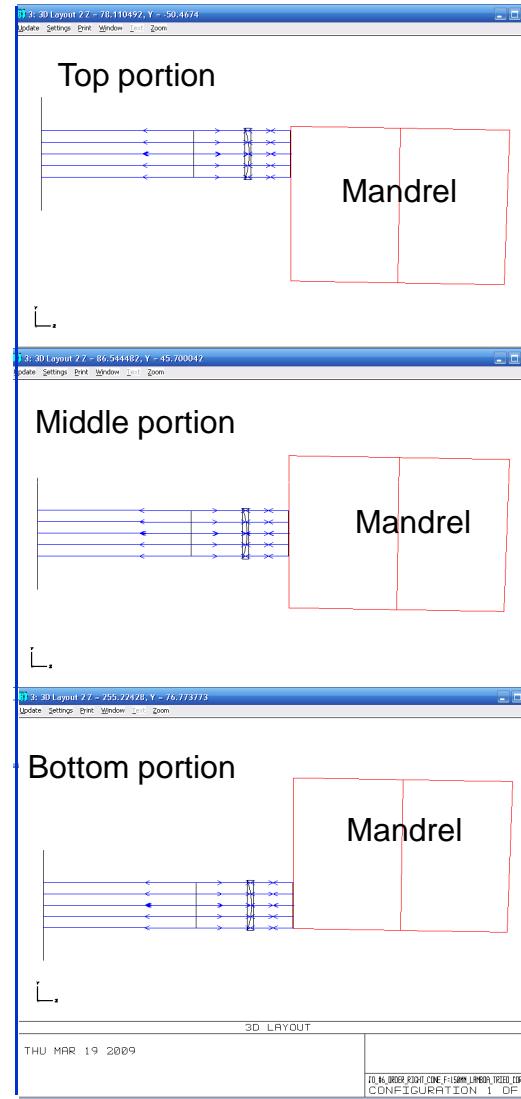
Simulation Results

Beam size at cylinder lens: ~1.8inch.
150mm fl cylinder lens

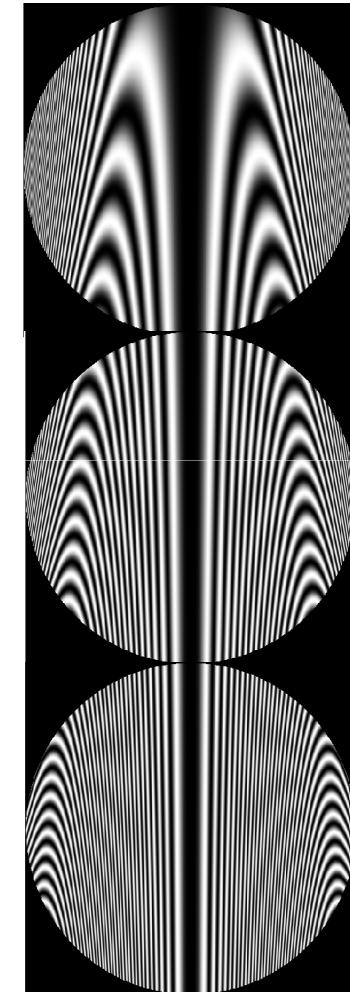
Top view



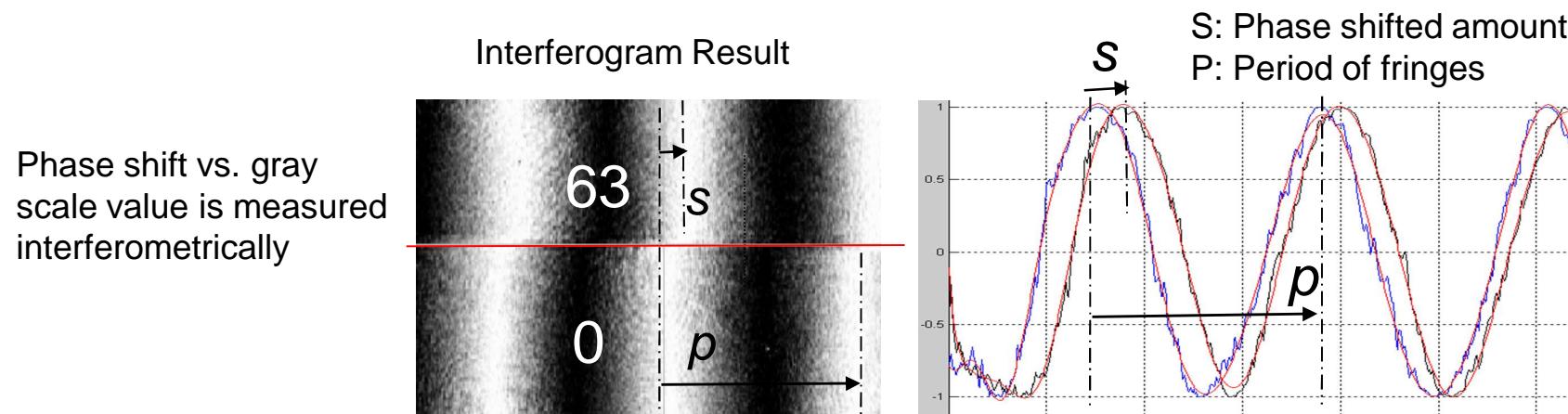
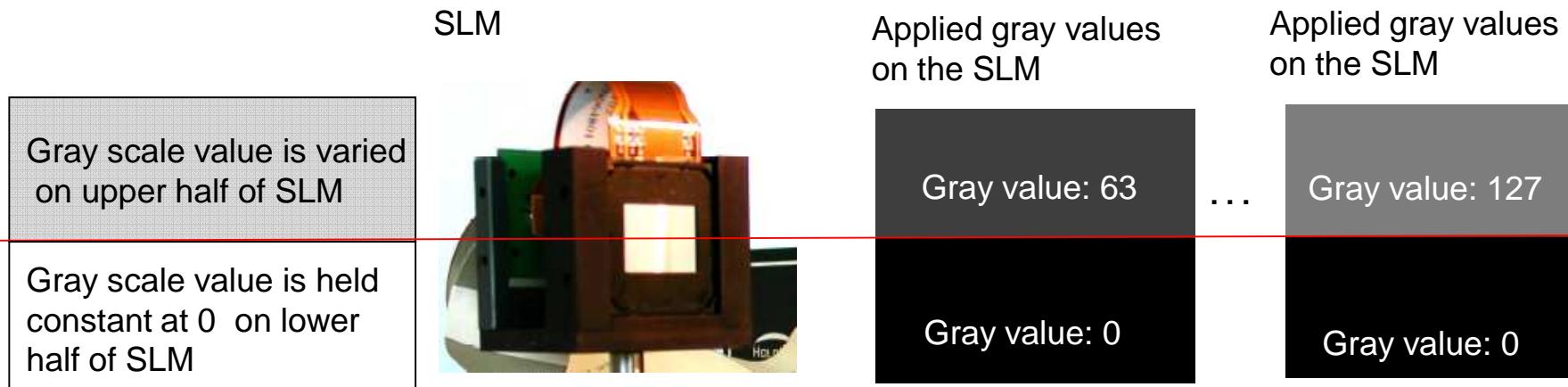
Side View



Interferogram

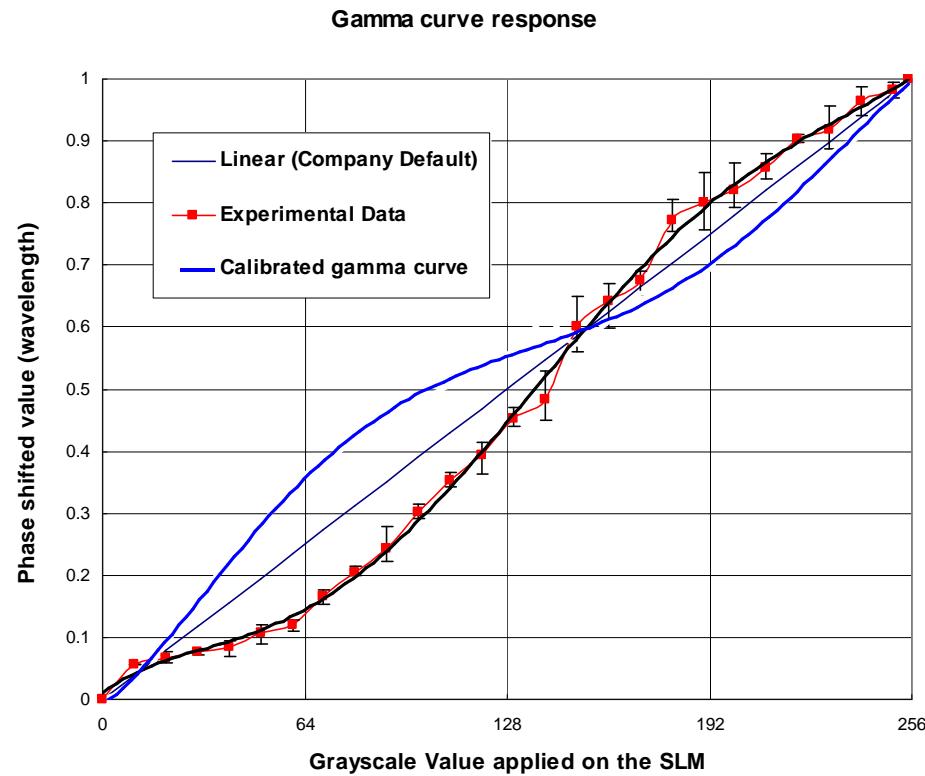


SLM Calibration



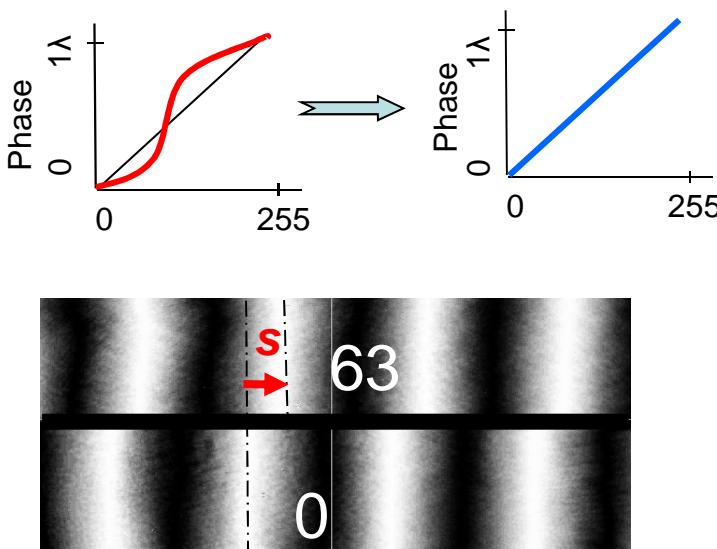
- Relative phase shift recorded to achieve an accuracy of data
- Gray value was varied from 0 to 255 on the top half, while it was held constant (0) on the bottom half
- Phase shifted vs applied gray value on the SLM produces gamma curve

Corrected Gamma Curve



The calibrated gamma curve (blue color), is used to linearize the phase vs. gray scale response (red curve)

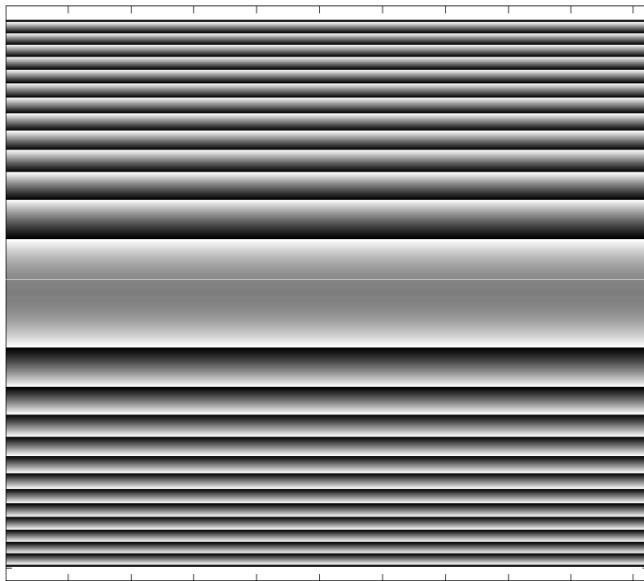
Errors when producing 1λ of tilt and corrected one after calibration



$S = 0.25\lambda$ shift when 63 value applied

Producing Cylindrical Wavefront

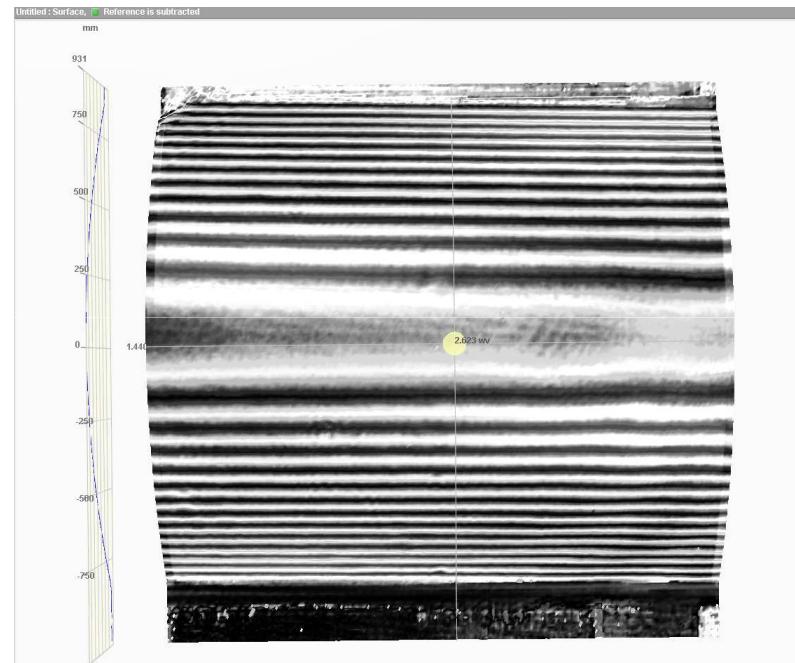
Applied Phase on the SLM



$$\phi \sim \alpha y^2$$

Matlab formula used to generate the phase.

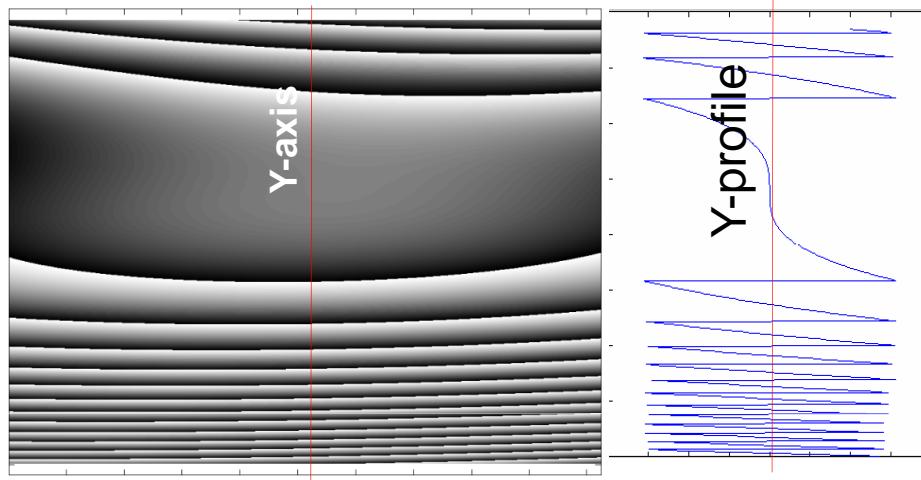
Interferogram on the pixelcam



- Cylindrical wrapped phase written by Matlab code and applied on the SLM, which is good candidate compensating phase for a Mandrel.
- Phase produced and shown by the interferogram on the pixelcam

Producing Arbitrary Wavefronts

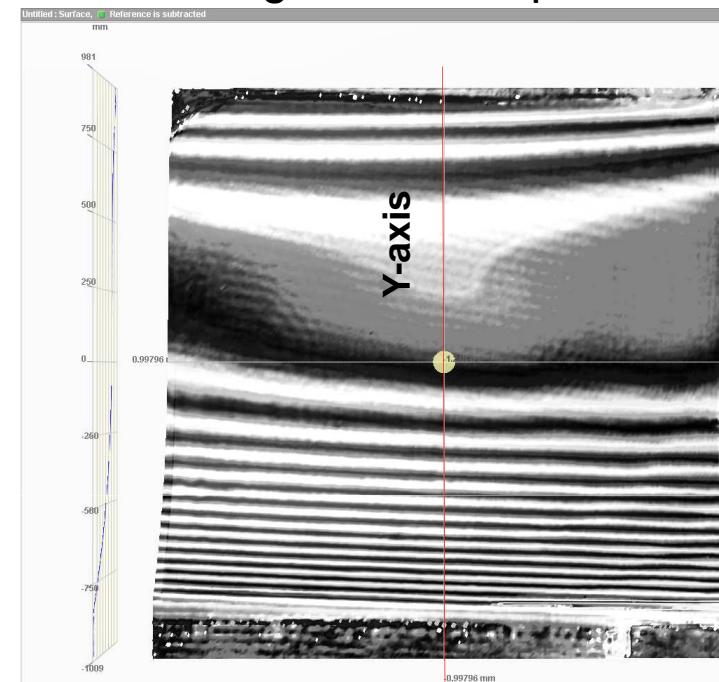
Applied Phase on the SLM



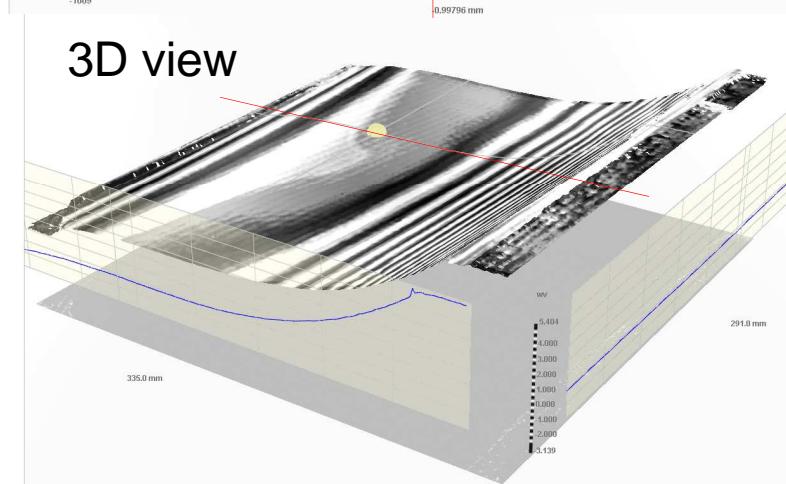
$\Phi = 20. * (y - 0.25)^3 - x.^2 + x.^y + x.^y^3$
Matlab formula used to generate the phase

- Arbitrary wrapped phase written by Matlab code and applied on the SLM
- Phase produced and shown by the interferogram on the pixelcam

Interferogram on the pixelcam

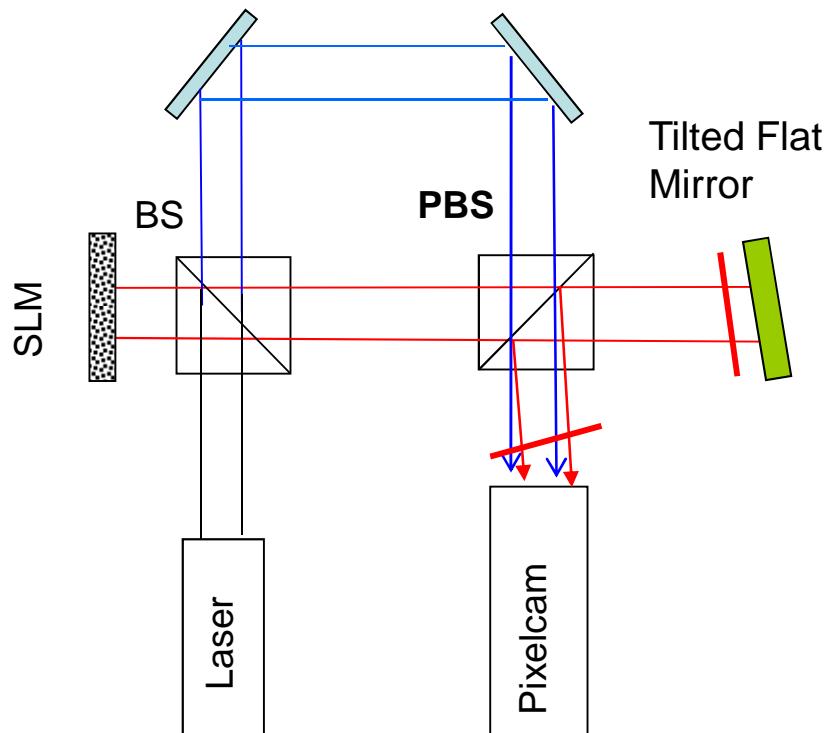


3D view



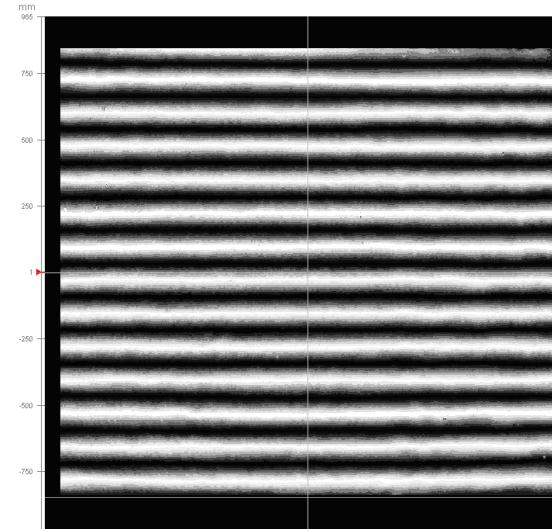
Compensation of Tilt

-Tilt by the flat mirror, ~7 waves



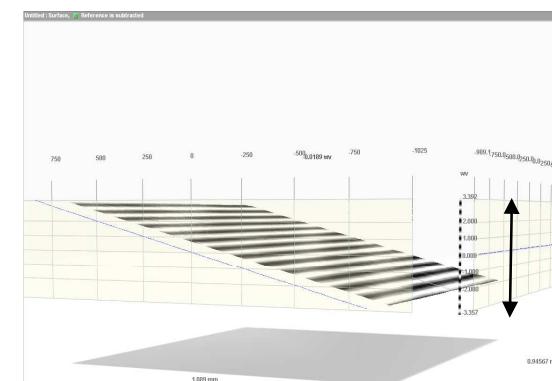
(Various waveplates and telescopes not shown)

Tilt introduced by flat mirror



Interferogram

~ 14 fringes

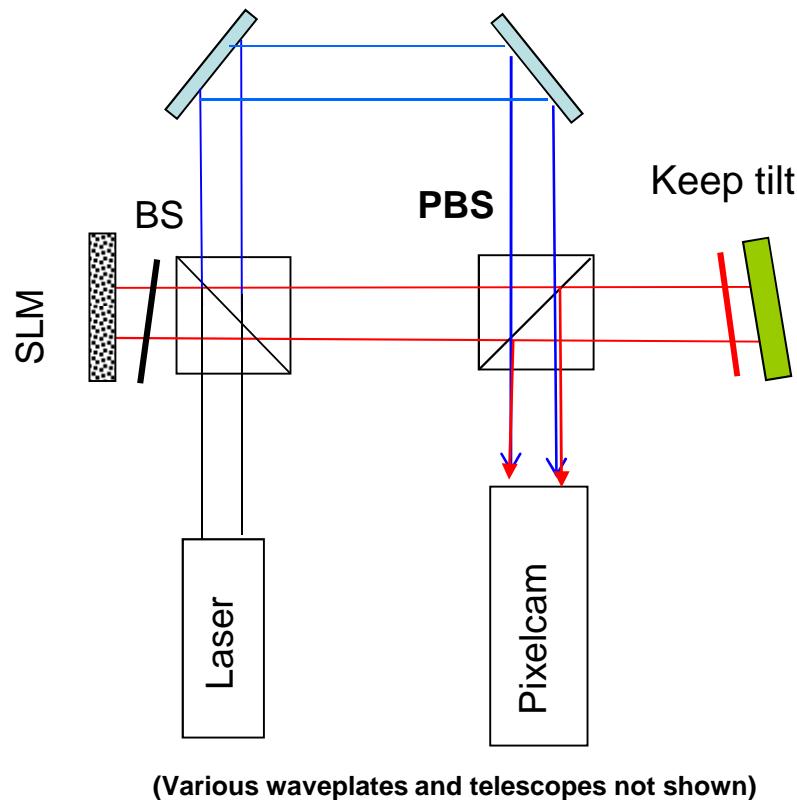


3D view

PV. $\pm 3.4 \lambda$

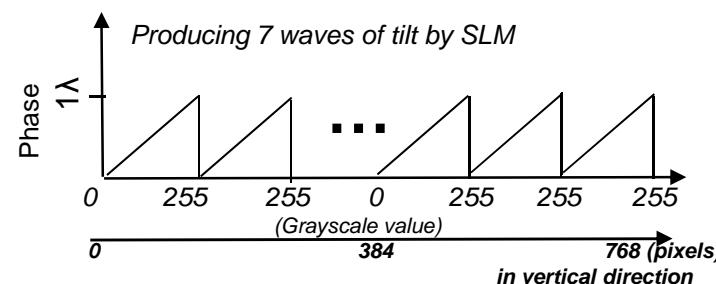
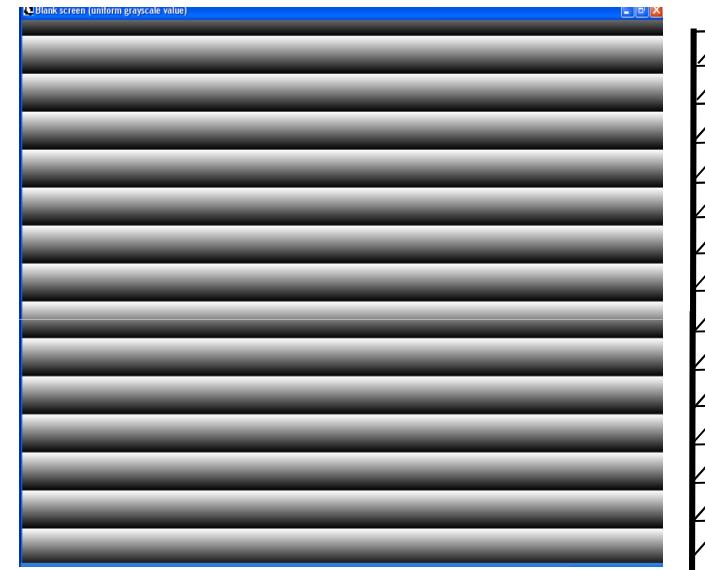
Compensation of Tilt

-Applied compensating tilt by the SLM



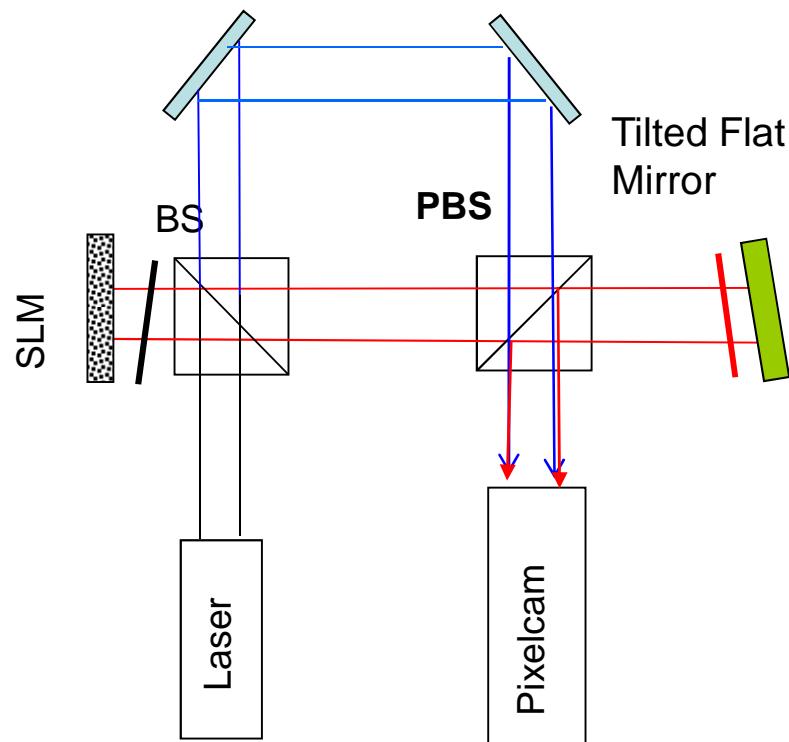
Compensating wrapped phase applied on the SLM

Wrapped phase applied on the SLM



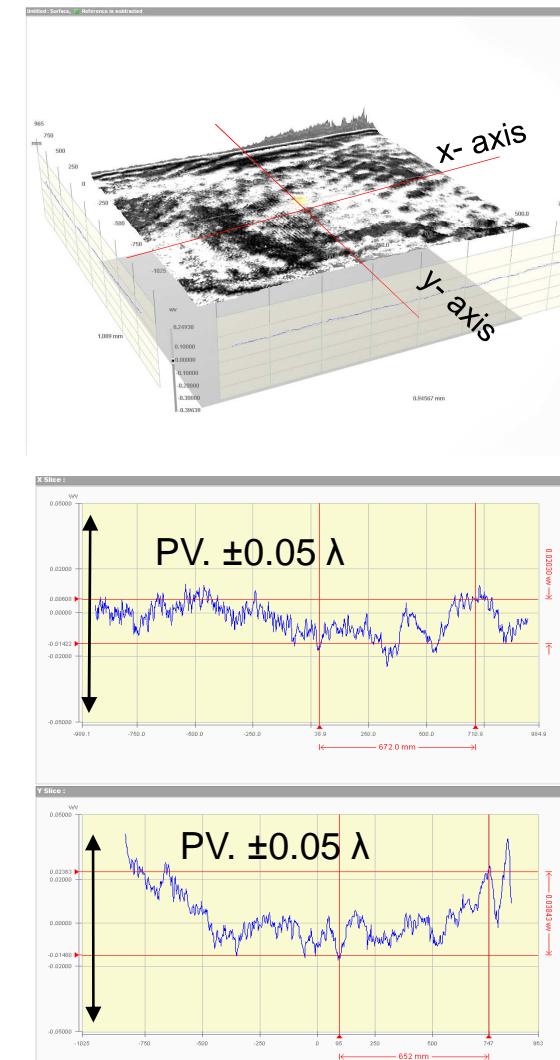
Compensation of Tilt

- Residual wavefronts, less than 0.05λ



(Various waveplates and telescopes not shown)

SLM can compensate tilted wavefronts
with an accuracy of 1/20th wave, or better

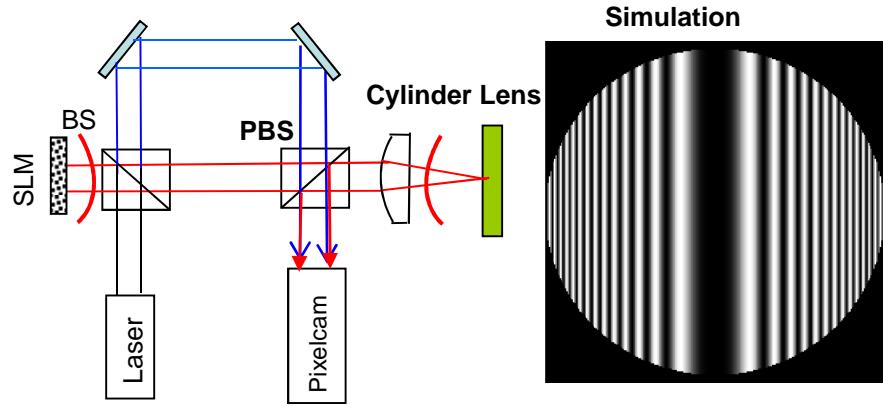


Interferogram
(3D view)

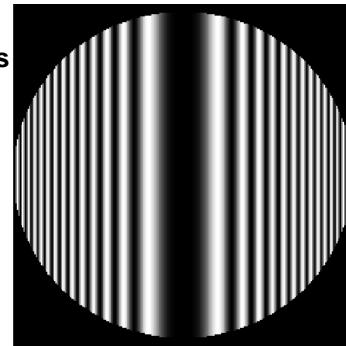
x- profile

y- profile

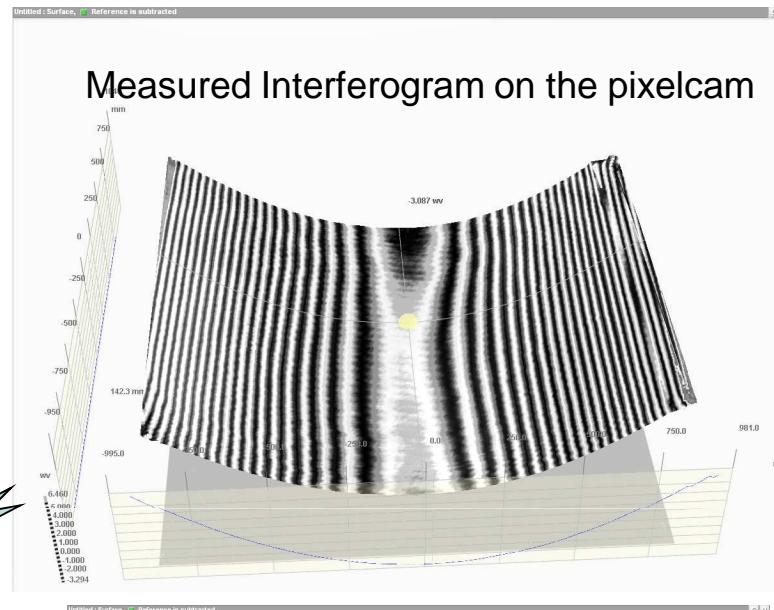
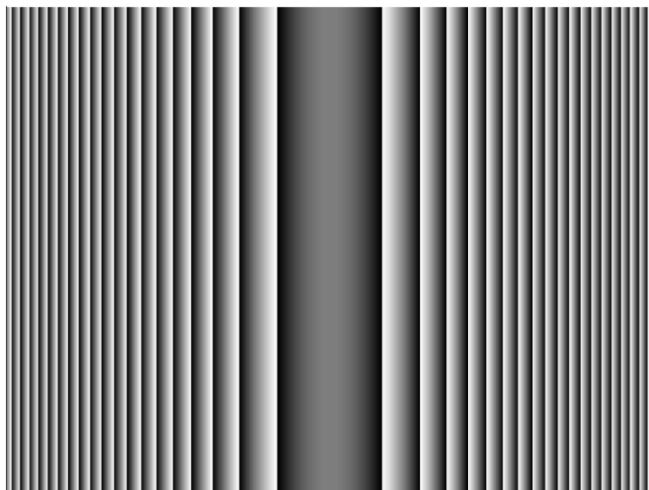
Compensating a Cylindrical Wavefront



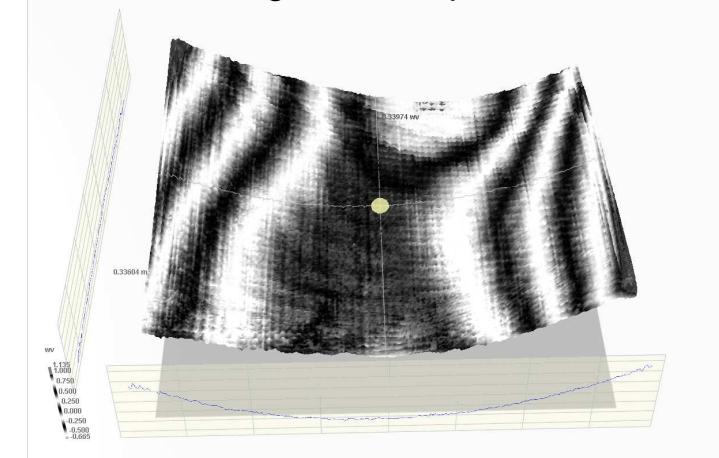
Simulation



Applied Phase on the SLM

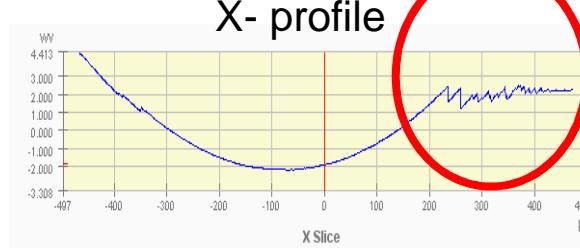
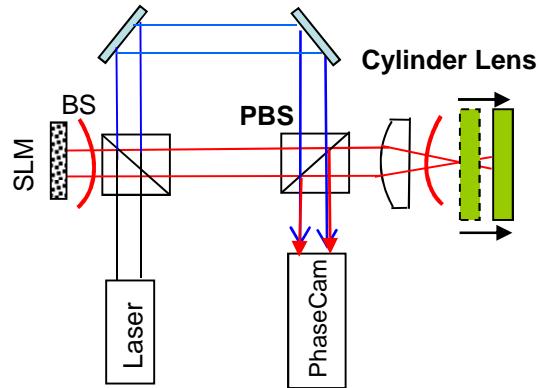


Residual fringes on the pixelcam

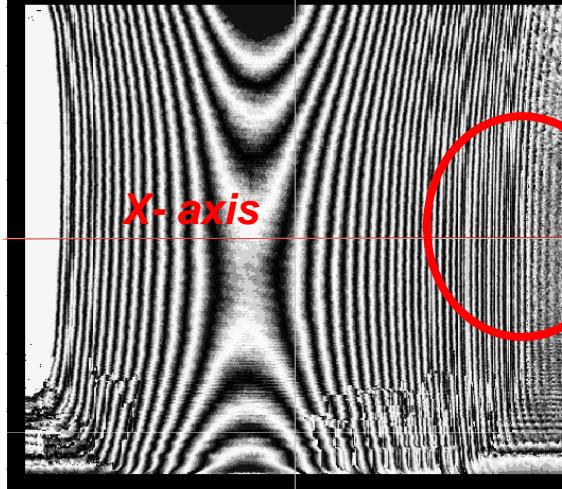


Compensating a Cylindrical Wavefront

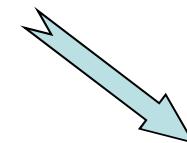
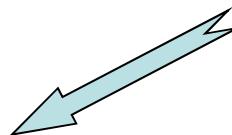
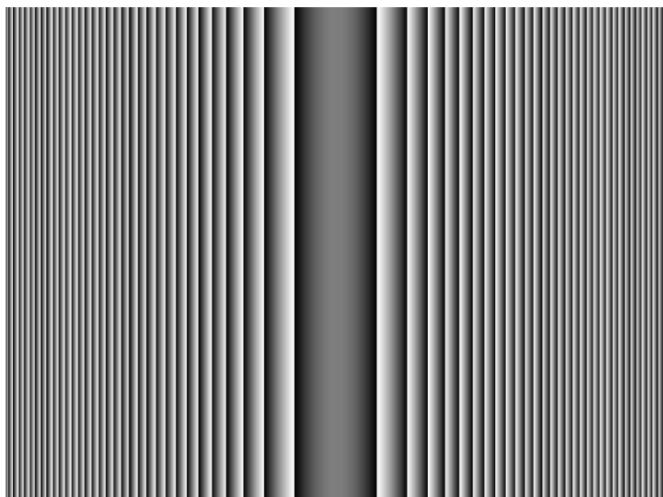
Extreme Case



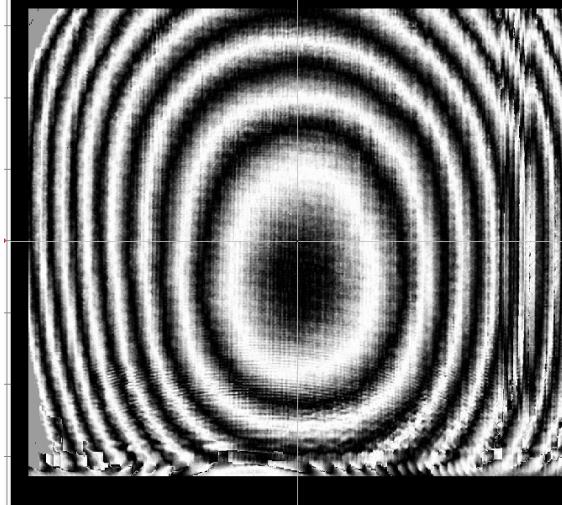
Measured Interferogram



Applied Phase on the SLM

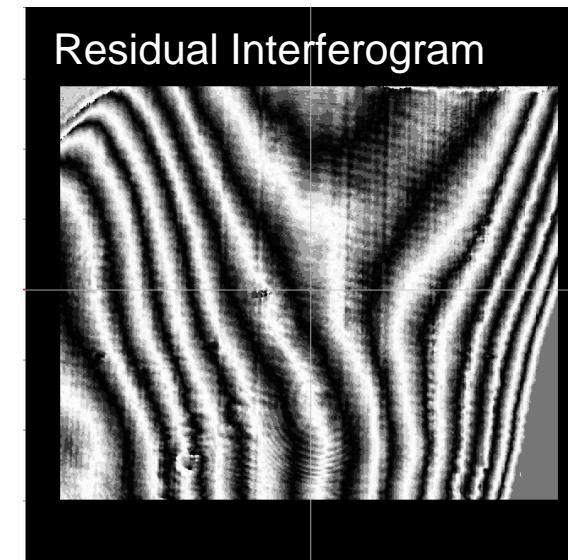
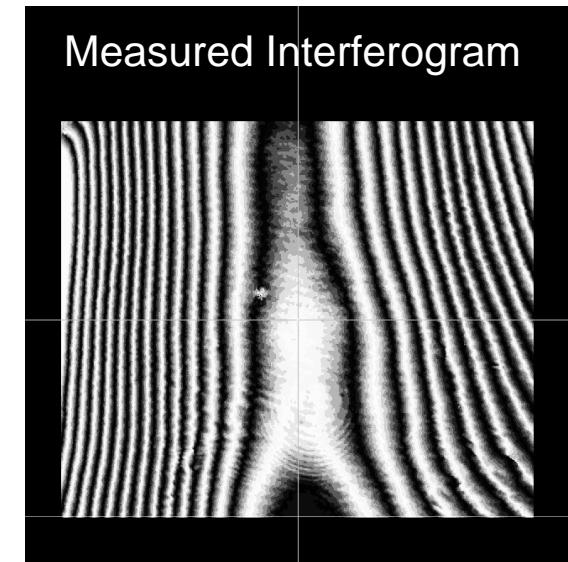
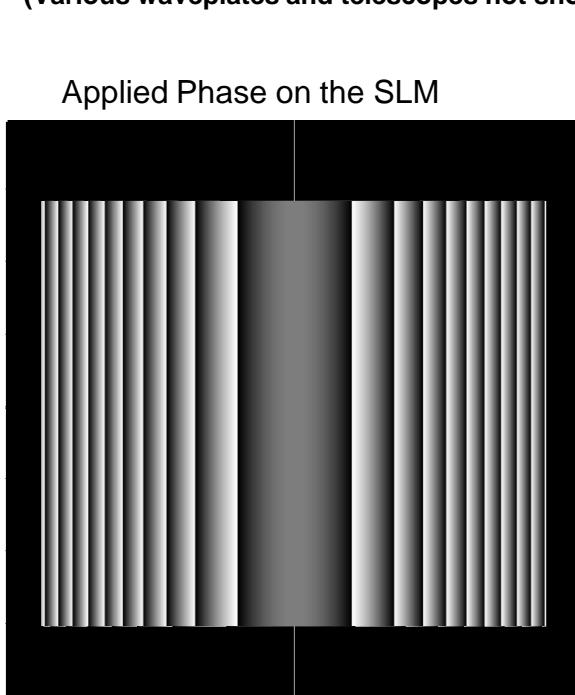
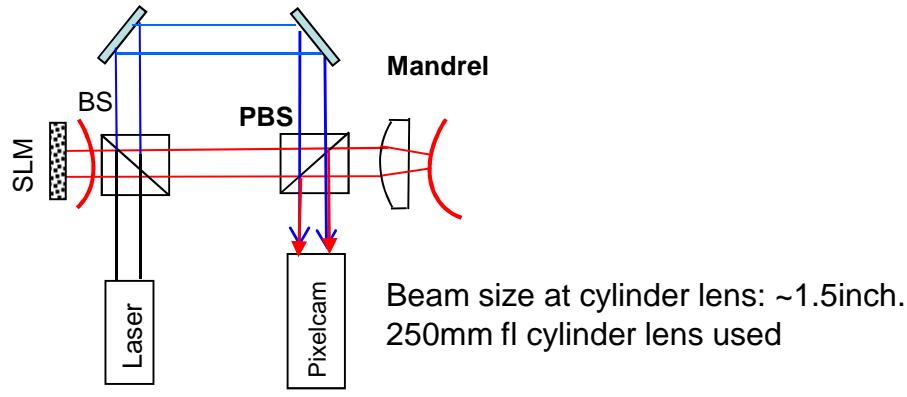


Residual Interferogram



The phase on SLM is used to bring the dense fringes down into the measurement range of the pixelcam. i.e: extended dynamic range.

Compensating for Mandrel





Conclusions / Problems to be solved

- Prototype metrology system complete - combines digital phase shift interferometry and a spatial light modulator.
- Demonstrated a dynamic interferometry as a wide range of advanced optical components.
 - showed that SLM used for compensator.
 - extended dynamic range.
 - Null point testing.
- Calibration of the SLM is done, by the corrected Gamma curve.
- SLM imperfection and system errors can be programmed out.
- SLM can compensate tilted wavefronts with an accuracy of 1/20th wave, or better.
- SLM can compensate cylindrical wavefronts as well as Mandrel's.
- *Stitching of experimental data will be next.*

Thank you

